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PSO based Droop Control of Inverter Interfaced Distributed Generations

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Abstract: *Often, there are several inverter interfaced distributed generations (IIDGs) in a Microgrid (MG). Each IIDG is connected to local loads and other IIDGs by one or several line. In this paper, an adaptive droop control method is presented that uses from line parameters between generation and consumption. Particle Swarm Optimization (PSO) is used to estimate optimal virtual line parameters. The impacts of active and reactive power fluctuations on voltage and frequency of MGs are presented. The results show that this method provides a desirable response of voltage and frequency under severe active and reactive changes in local loads.*

Keywords: Microgrid, Inverter Interfaced Distributed Generation, Droop Control, Virtual Line Parameter, Particle Swarm Optimization.

1. Introduction

According to the IEEE STD 1547-2003 standard [1], island is a part of network that has been separated from other parts, and only distributed generations (DGs) supply it. This standard says that an island should be able to establish two seconds after occurring of any event, and DG units are separated from main grid. At the islanded operating mode, the microgrid (MG) has been absolutely isolated from main network, and energy transfer between MG and main grid has been blocked. Therefore, main problem of the islanded MG is stabilizing against severe frequency and voltage fluctuations to supply high reliability electric energy.

Some challenges of MGs on operation and control are presented in [2-4] such as voltage and frequency control in both connected and islanded modes. The impacts of energy storage devices on dynamic MG response are studied in [5]. In connected mode, for regulating voltage and frequency of the MG, the direct-quadrature-current control method is used [6, 7]. Conventional and intelligent techniques are used in voltage and frequency stabilizing such as [8-13]. Application of Intelligent algorithms such as artificial neural networks (ANNs) in the power systems have been used frequently in the control field. In [14], the ANNs are used for the voltage stability assessment. Using intelligent techniques such as fuzzy Logic (FL) and ANNs to control interconnected power systems generation are reported in [15].

In islanding operating mode, the voltage source inverters (VSIs) mostly are used [16]. In this case, voltage and frequency of the MG are controlled by local controls. To avoid circulating currents between parallel inverters connected to the MG, control strategies based on droop characteristics is mostly applied [17].

Different classifications for MGs are defined. These classifications can be based on capacity, voltage level, load sensitivity, control method and etc. Another classification is also defined based on the MG structures and connection of generation and consumption sides. There are some differences between MG and conventional power system. For example, an inverter interfaced DG (IIDG) do not has often the large rotating mass and has dynamically faster response. The IIDGs are connected to the local loads by means of the lines. Due to standing MGs in distribution systems, these lines can be often resistive. Also, sometimes that the lines are long, can be inductive. According to that, the MGs are divided into resistive and inductive MGs. Recently; several control techniques based on droop characteristics have been used to improve the voltage and frequency regulation performance in MG systems. In the previous published works [17-21], MGs are usually considered as resistive or inductive systems. In inductive MGs, due to existence of a strong linkage between reactive power and voltage, the conventional Q/V droop control based strategies are used for voltage control. While, in resistive MG, the P/V droop control techniques are used for this purpose. Since, the frequency fluctuation is mainly caused by the fluctuation in real power, the P/f droop control methods are used for frequency control. However, it can be shown that a strong linkage exists between reactive power and grid frequency. Thus, Q/f droop techniques are also needed for MGs frequency control design.

In [22], a droop control method named generalized droop control with a different structure from the previous

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works is presented. In the generalized droop method, the frequency and voltage is simultaneously controlled under the severe changes in loads. In other words, both the active and reactive powers are used for voltage/frequency droop control. The main problem of this method is dependency on the line parameters. So that, in MGs including several DG units and loads, due to the existence of several lines in the system, the virtual line parameters should be used. Then, for optimal estimation of these parameters, evolutionary algorithms can be used. Particle swarm optimization (PSO) is a simple and efficient methodology to evaluate virtual line parameters of the MG.

In the present work, an adaptive droop control strategy based on virtual line parameters by PSO is proposed to regulate the voltage and frequency of the islanded MGs. This paper is organized as follows: In Section 2, a generalized droop control based on resistive/inductive ratio is presented. And in Section 3, to apply the generalized droop control to larger MGs with several DGs and lines, virtual line parameters should be estimated. To estimate the virtual line parameters, PSO algorithm is used.

2. Generalized Droop Control

In an MG, there are small generative units with power electronic interfaces (inverters) that are called IIDGs. These sources are placed at local areas; they have advantages such as low cost for consumer and generator, low voltage, high reliable with little emission, increase in redundancy and robustness of system and high flexibility [23].

Two strategies may be used for inverter operation; one is PQ inverter control that is used to supply a given set-point for active and reactive power. It can be operated with a unit power factor or receive a set-point for the output reactive power. Mostly, the PQ inverter is used in connected mode; due to existence a fixed defined set-point, it does not have ability of adjustment in accordance with changes in the conditions. But, there is another control structure to operate in the islanded mode known as VSI control [24]. The VSI provides control of both the magnitude and phase of the inverter output voltage. It can be also used in the non-islanding operation mode. Except that, in this mode, the reference values of voltage and frequency are imposed by the main grid to the MG.

Fig. 1 shows a general block diagram presented in [22] for a VSI. The LCL output filter has been added to prevent the resonance impact in the output network. Also, the LCL damps the distortion of output sinusoidal waveform and reduces high frequency harmonics caused by switching operations of the VSI. Therefore, it is used in the inverter output for preservation of quality of output current and bus voltage when links to the weak grids [25].

In Fig. 1, K_f and K_v are droop coefficients and K_R is an index to determine the resistivity/inductivity of the MG and is equal to line resistance/inductance ratio between IIDGs and local loads. In this control structure, a more real model for droop control in the IIDGs is presented. The participation percentage of the active/reactive power in the voltage/frequency droop control has been determined by the lines resistivity/inductivity index [22].

The main problem of this method is dependency on the line parameters. Consider an MG with three DGs and two loads as shown in Fig. 2 [26]. In MGs including several IIDG units and loads, due to the existence of several lines in the system, the virtual line parameters should be used. Then, for optimal estimation of these parameters, evolutionary algorithms such as PSO can be used. Evolutionary algorithms can be efficient for optimal estimation of line parameters needed in generalized droop control method.

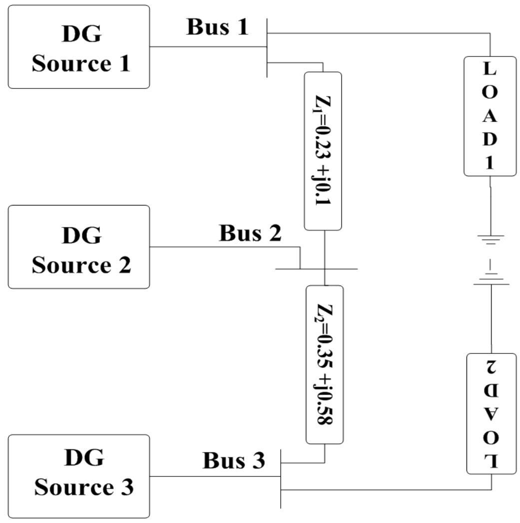

Fig. 2: An islanded MG with three DGs and two load banks

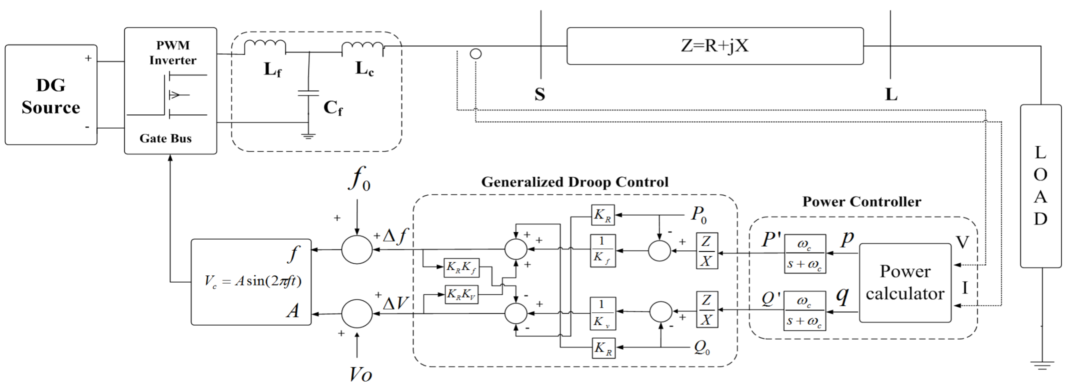

Fig. 1: General block diagram of VSI for a simple MG [2]

3. Virtual Line Parameters Estimation Using PSO

PSO is one of optimization techniques based on evolution nature systems that developed by Kennedy and Eberhart at 1995 [27]. In the PSO algorithm, there are number of organisms that called particles. These particles are propagated randomly in the search space of objective function that to be minimized. Each particle calculates value of objective function in its current position. Then, using combination of current information, the best previous position and information of one or several of available best particles, it will choose a direction to move. All of particles will choose a direction to move and after moving, a step of the algorithm ends. These steps are repeated several times until the desired response is achieved.

In the PSO, each particle is composed of three vector of *d* dimensional that *d* is dimension of search space. For particle i^{th}, these three vector are current position ($x^i[t]$), moving velocities ($v^i[t]$) and previous best position ($x^{ibest}[t]$). In each iteration, the $x^i[t]$ is given in the objective function and is calculated as an answer to the problem. If this position is better from previous answers, it is saved in $x^{ibest}[t]$. The $f^i[t]$ and $f^{ibest}[t]$ are objective function values for $x^i[t]$ and $x^{ibest}[t]$ at t^{th} iteration, respectively.

In initializing step, the particles are created with random positions and velocities. Following starting the algorithm, the position and velocity of all particles are made from previous step information. According to Equations (1) and (2), the position and velocity of the particles are updated, respectively.

$$v^i[t+1] = \omega v^i[t] + c_1 R_1 \otimes \left(x^{ibest}[t] - x^i[t]\right) + c_2 R_2 \otimes (x^{gbest}[t] - x^i[t]) \quad (1)$$

$$x^i[t+1] = x^i[t] + v^i[t+1]) \quad (2)$$

where, $\otimes$ represents array multiply for matrixes, ω inertia coefficient, R_k and c_k (k=1,2) are uniform random vectors equal to search space dimension and training coefficients, respectively.

The generalized droop control technique presented in [21] is dependent to the line parameters R and X. Consider the MG with three IIDGs and two loads as shown in Fig. 2. The IIDGs (220V, 50 Hz) are interfaced to two local load banks, at bus 1 and bus 3. System parameters are same as the parameters given in TABLE I.

It is obvious that in this MG, unlike the simple MG (Fig. 1), relationship between generation and consumption is not accomplished only via one line. For example, IIDG 2 divides its generation power between load 1 and load 2. Thus, between generation and consumption cannot be specified with a special resistance R and inductance X. In such cases, a virtual R and X should be considered in control structure of IIDG to achieve a desirable response. According to the generalized droop control structure, for an IIDG, a line should be existed between generation and load. Therefore, there are six line parameters that must be determined ([R_1 X_1 R_2 X_2 R_3 X_3]). In the present work, the main goal is simultaneous control of frequency and voltage, which can be formulated as the following optimization problem:

Minimize

$$f(x) = \sum_i \alpha_i \,|df_i(x)| + \beta_i \,|dv_i(x)| \quad \forall i = 1,2,\ldots,n \quad (3)$$

subject to

$$\begin{aligned} &|df_i| \le E_f \;\; \& \;\; |dv_i| \le E_v \\ &0.01^{\Omega} \le R_i \le 5^{\Omega} \\ &0.01^{\Omega} \le X_i \le 0.3^{\Omega} \end{aligned} \quad (4)$$

where, x is the virtual line resistance (R) and reactance (X) of IIDGs (x=[R_1 X_1 R_2 X_2 R_3 X_3]), $f(x)$ is the objective function, df_i is the frequency deviation of the ith IIDG output, dv_i the voltage deviation of the ith IIDG output, α_i is the stress coefficient of frequency in node i, β_i is the stress coefficient of voltage in node i, n is the total number of IIDGs in the MG, E_f is the maximum allowable frequency deviation, and E_v is the maximum allowable voltage deviation.

For the problem at hand, due to existence of local loads at buses 1 and 3, the α_2 and β_2 are considered as half of $\alpha_1 - \alpha_3$ and β_1 - β_3, respectively. Thus, their droops are more than bus 2. The parameters values of Equations (3) and (4) are shown in TABLE II. Here, the PSO algorithm is used to find the minimum value of defined objective function of Equation (3). Flowchart of the PSO algorithm to find optimum line parameters is shown in Fig. 3.

TABLE I: Inverter Parameters for IIDGs in Fig. 2

Parameter	Value	Parameter	Value
$V_{L\text{-}L}$	380 v_{rms}	C_f	30 μF
f	50 Hz	r_{cf}	5 Ω
P_{nom}	30 kVA	L_{Lc}	3mH
f_s	4 kHz	r_{Lc}	0.1 Ω
L_f	6mH	K_f	-1.06
r_f	0.2 Ω	K_v	-100

TABLE II: Objective Function Parameters

Parameter	Value	Parameter	Value
α_1	66	β_2	50
α_2	33	β_3	100
α_3	66	E_f	0.1 Hz
β_1	100	E_v	20 v

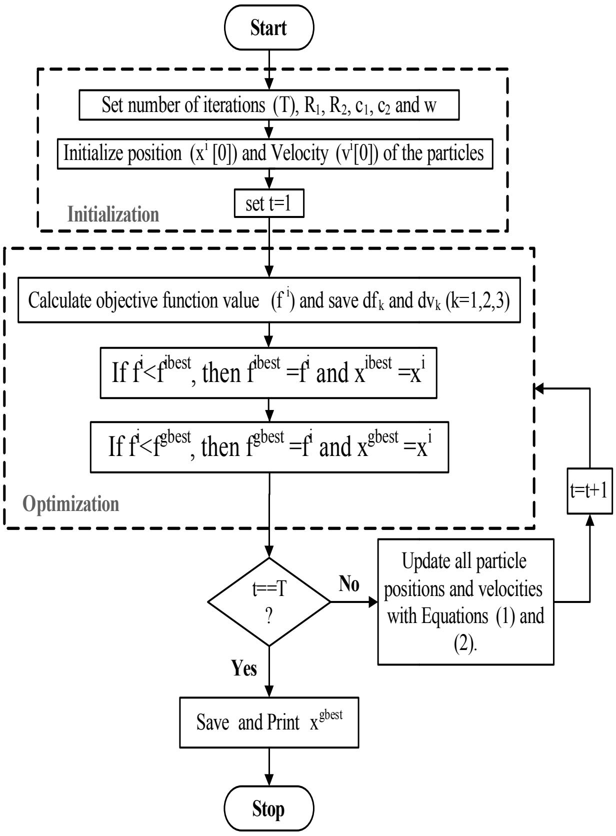

Fig. 3: The applied PSO algorithm

To test the PSO algorithm performance, optimization process is designed. The concrete parameters are set up as follow: the numbers of the swarm particles are 5, $c_1 = 1.5$, $c_2 = 2.5$, $\omega = 0.8$.

For the problem at hand, the numbers of the swarm particles are 5. The stop condition is met with maximum iteration of 20 epochs. The simulation results after applying the PSO algorithm to the test system (Fig. 2) are shown in Figs. 4 and 5. Fig. 4 shows how the objective function value varied with iteration and Fig. 5 shows the motion trajectory of the global best position $x^{gbest} = [R_1^{gbest}\ \ X_1^{gbest}\ \ R_2^{gbest}\ \ X_2^{gbest}\ \ R_3^{gbest}\ \ X_3^{gbest}]$. Finally, optimal result is obtained as $x^{gbest} = [0.0118\ \ 0.0107\ \ 4.9736\ \ 0.1372\ \ 4.5040\ \ 0.0327]$.

To test and verify the effectiveness of the proposed droop control method based on estimating virtual line parameters; first, pure active loads are considered: 30 kW and 10 kW active loads at bus 1 and bus 3, respectively. Then, with occurring violent changes in both loads at different times, the impact of dynamic load changes with estimated parameters on the MG performance is evaluated.

The active and reactive load changes are shown in TABLE III. The system response including voltage/frequency profile is shown in Fig. 6. The Fig. 6 shows that the steady state voltage and frequency are normal. Fig. 7 shows nominal values for the steady state voltage and frequency, and the deviations are too small.

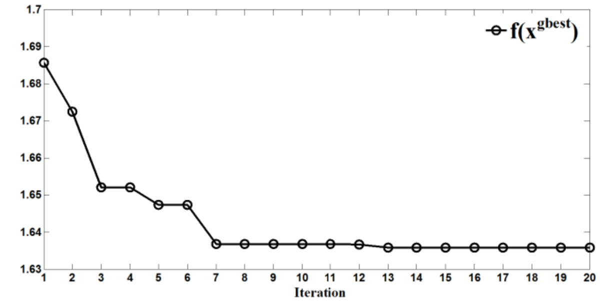

Fig. 4: Convergence of defined objective function

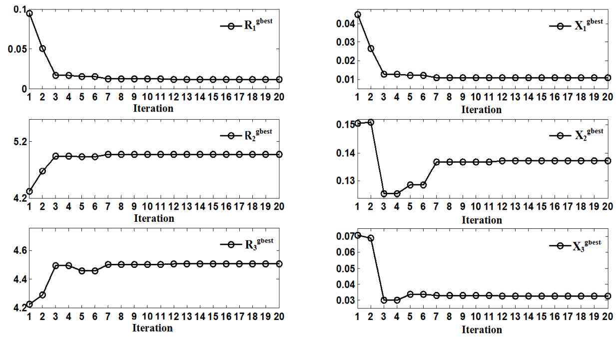

Fig. 5: The motion trajectory of global best position for minimizing the defined objective function

TABLE III: Load Change Scenario

Time duration [s]	Load 1 [kVA]	Load 2 [kVA]
0-0.3	30	10
0.3-0.5	30	j40
0.5-0.7	30 +j10	10
0.7-0.9	30	j10
0.9-1.1	0	10
1.1-1.3	30	10

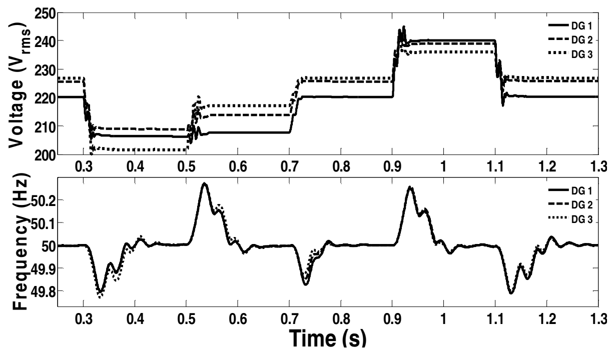

Fig. 6: Voltage and frequency profile under violent load changes

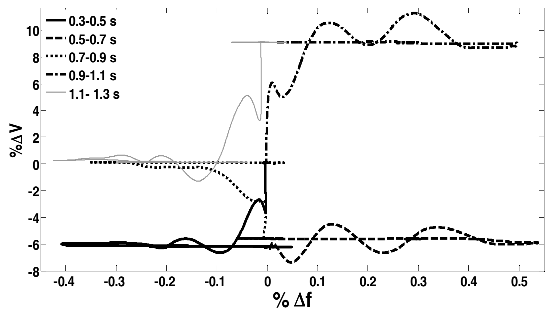

Fig. 7: Voltage/ frequency deviations curve under load change scenario Table III (IIDG 1)

Now, consider the outage of an IIDG from the MG system, following an event. To see the voltage and frequency profiles after outage of an IIDG, and to check either the remained islanded MG is stable or not; IIDG1 is removed from the MG in time duration of 0.4 to 0.6 seconds.

Simulation results for this scenario are shown in Fig. 8 and Fig. 9. After removing IIDG1 at t=0.4s, other IIDGs are going to compensate the IIDG1 absence and stop the voltage/frequency deviation. When IIDG1 is removed, due to lack of secondary control loop, a steady droop is observed in the loads terminal voltage. In this work, an adaptive primary control based on the droop characteristics is only considered. Voltage and frequency indices remained stable under serious local load fluctuation, also system frequency returns to nominal values rapidly (Fig. 9).

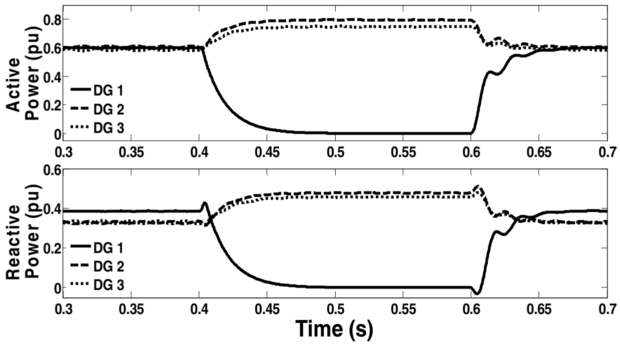

Fig. 8: Output active and reactive power affected by outage of IIDG 1

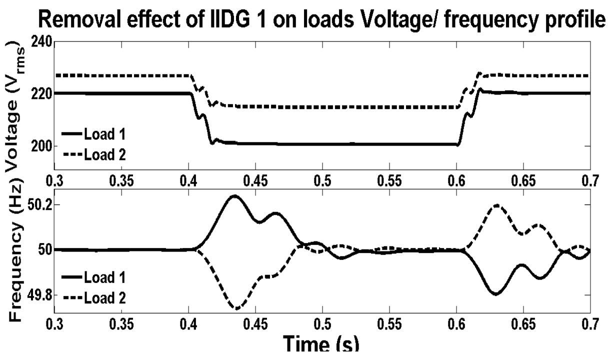

Fig. 9: Voltage/ frequency profile of local loads affected by removing IIDG 1

4. Conclusion

The present paper provides a solution for voltage and frequency droop control synthesis. First, based on the well-known conventional voltage/frequency droops, a generalized droop control is proposed. Then, PSO algorithm is applied to compensate the generalized droop control weak point in application to large-scale microgrids. PSO algorithm is used to estimate virtual line parameters. The effectiveness of the proposed method is examined against severe changes in local loads.

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